AN RF POWER SYSTEM FOR NSP HIGH INTENSITY PROTON ACCELERATOR AT JAERI

E. Chishiro, Y. Touchi, H. Kaneko, J. Kusano, K. Hasegawa and M. Mizumoto

JAERI, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan

Abstract

JAERI has been proposing a high-intensity proton accelerator with energy of 1.5GeV and a beam power of 8 MW for the Neutron Science Project (NSP)[1]. This paper describes a conceptual design study for the RF system; a candidate of amplifier for the low energy accelerating part, an RF system efficiency and required AC power are estimated for the high energy accelerating part.

1 RF SYSTEM OF NSP ACCELERATOR

The NSP is aiming at exploring nuclear technologies for nuclear waste transmutation and various basic research fields such as condensed matter physics based on a proton induced spallation neutron. The accelerator will consist of RFQ, DTL for the low energy part and superconducting (SC) linac for the high energy part. It should be operated both in pulse and CW. The RF system is most costly part for a high power RF accelerator and one of the major components to determine the reliability.

The accelerator is required with CW operation for application of the nuclear waste transmutation, and is required with high current pulse operation for the basic research field. This requirement is the essential feature of the NSP accelerator. A preliminary specification for the accelerator is given in Table 1. The final value of energy/current and pulse time structure will be determined from further discussion on the user requirement and the cost estimation.

Figure 1 shows a block diagram of an RF system for the NSP accelerator. As a main option, we chose a frequency combination of 200 - 600 MHz for the accelerator. There is three times frequency jump between low and high energy part. In the first consideration, we chose a klystron system in the 600 MHz part. Klystrons are widely used as high power RF source and are regarded as a reliable device. Grid tubes such as a tetrode and a Diacrode will be applied in 200 MHz part. In the conceptual design, the accelerator requires the total peak RF power of about 300 kW for RFQ, 9MW for DTL and 29 MW for SC linac for the pulse operation.

Table 1. Preliminary specification of NSP accelerator.

Energy	1.5GeV
Accelerating particle	H^- , H^+
Low-energy part	RFQ, DTL (200 MHz)
High-energy part	SC linac (600 MHz)
Averaged current	5.33 mA
Peak current	5.33 mA at CW operation
	30 mA at pulse operation
Repetition rate	50 Hz
Macro pulse width	5.9 ms
Intermediate pulse width	400 ns (interval 270 ns)

2 LOW ENERGY PART

Selection of the amplifier in 200 MHz part is one of the important issues. Grid tubes will be used in 200 MHz RF system. However, a large amount of power dissipation in the tube caused by 1MW, CW operation will be a serious problem.

The first candidate of the tube is the EIMAC 4CM2500KG. We have utilized the tube to operate an RFQ (201MHz, 500kW, 10% duty) in JAERI. The tube has been used the plasma heating in the fusion applications, which has been demonstrated 1.7 MW output power with pulse width of 5.4 second. However, particular estimations are necessary to adopt the tube, because of the operating frequency is different from the NSP operation condition.

In the initial estimation, we considered the power

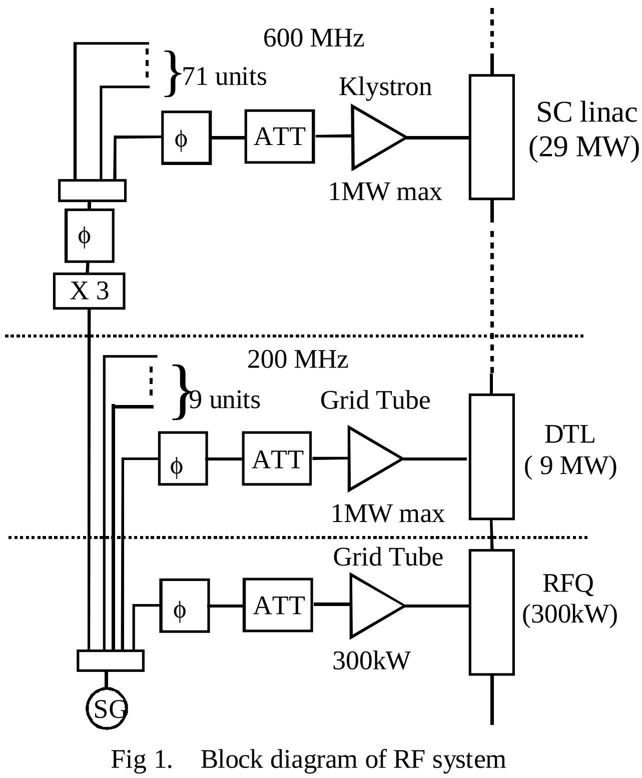

Fig 1. Block diagram of RF system for NSP accelerator.

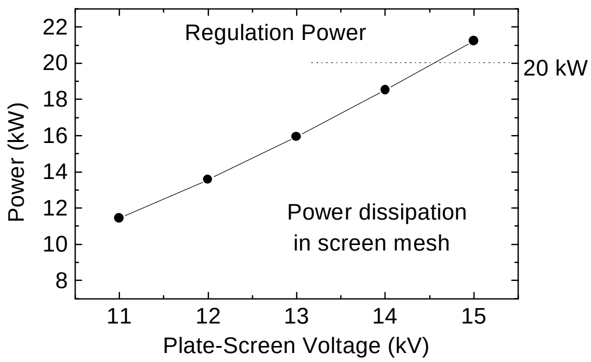

Fig. 2. Dependency of power dissipation on plate - screen voltage for 4CM2500KG.

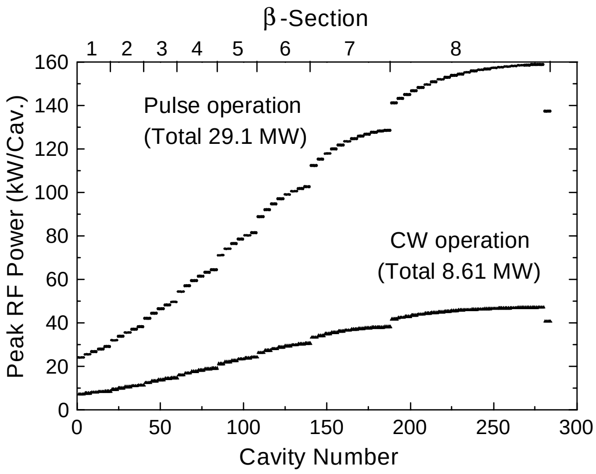

Fig. 3. Peak RF power for each cavity.

dissipation on the screen grid mesh in the tube using the SUPERFISH code. Figure 2 shows the dependency of the dissipation on the screen-plate voltage (RF swing voltage). Under the ≈14kV, the dissipation satisfies the regulation value of 20 kW and the plate current will be around 100 A. The 4CM2500KG is regarded as one of the adequate tubes from above the simulation.

The second candidate of the tube is a Diacrode, which is recently developed in the Thomson Tubes Electroniques. The tube has a unique feature that is low dissipation density on the mesh of the screen grid. We simulated the dissipation and its density under the some assumptions (internal structure, mesh area). In the result, the dissipation is also below the maximum rate at swing voltage of ≈14kV and the density is about 1/5 times of 4CM2500KG's.

To demonstrate the CW, 1MW operation, high power test using either tube has to be carried out.

3 HIGH ENERGY PART

3.1 RF parameter of SC cavities

The SC linac consists of 284 cavities that is divided into 8 sections based on an optimization study for the linac length and the beam emittances [2]. To distribute an equal RF power to every four cavities, the cavity field gradient and the transit time factor are adjusted.

We calculated the required peak RF power for each operation mode. To minimize the RF power, we considered optimum conditions that an input coupler is matched and the SC cavities are pre-detuned for the beam load, but detuning effect caused by Lorentz force and microphonic is neglected. The result is shown in Fig. 3. The cavity number #1 means low-β end of the linac and #284 means high-β end. The required power is gradually increasing with cavity number and the power at the high-β end is 6.6 times as large as that at the low-β end. For the pulse operation, the maximum RF power of 158 kW/cav. is needed at the high-β section. The other hand, the RF power of 47 kW/cav. is required for the CW operation. There is difference of 3.4 times in the required power between CW and pulse operation. The 600 MHz system (amplifier, DC supplier etc…) has to manage for the difference. The total RF powers for pulse and CW operation are 29MW and 8.6 MW, respectively.

3.2 RF system of high energy part

The RF system of high energy part will take the greater part of capital and operating cost of the NSP accelerator. In the conceptual design, we assumed output power of a klystron is distributed to four cavities. Here, we evaluated the efficiency and the AC power on this situation. However, how many cavities can be driven by a klystron is still under consideration.

In this design, the klystrons of 71 units are needed for 284 cavities, and two classes of klystron (1MW class and 400kW class) are used in the RF system, because the RF power varies along the linac. The klystron is required high power, pulse operation and low power, CW operation. In addition, one class of klystron has to be covered with wide power range. In generally, the operating efficiency depends on the output power. To keep the high efficiency, the beam voltage (cathode voltage) and anode voltage are controlled corresponding to the required output power. Figure 4 shows the dependency of the efficiency on the saturation output power. This value refers to a klystron characteristics of 1 MW maximum output and 500 MHz operating frequency.

An RF power margin is required for the field control to regulate the amplitude and the phase. Thus the klystron can not operate at the saturation power, and the efficiency decreases from the value seen in Fig.4. For instance, if a klystron with saturation efficiency of 65 % is operated at 80% of the saturation power, the efficiency becomes to 52 %. How much the margin is needed for the control is still discussed, but we estimated the AC power and the efficiency of the system assuming the 25% margin.

Figure 5 shows the peak beam power and the klystron efficiency. An arrangement of klystron is decided by its maximum power; the 400 kW tube is nominated from

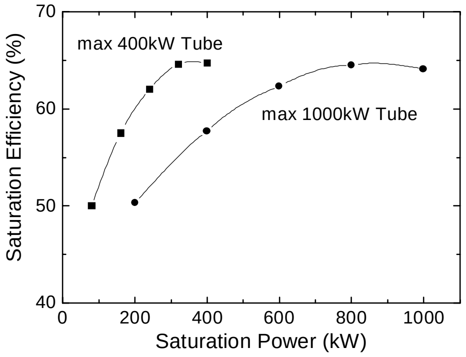

Fig. 4. Dependency of operating efficiency on saturation power. Beam voltage and anode voltage are controlled to saturate at a required power.

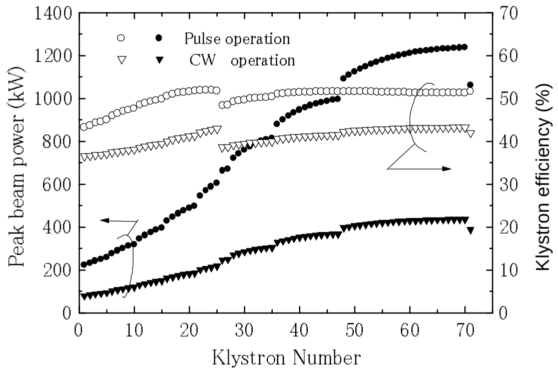

Fig. 5. Peak beam power and klystron efficiency for each klystron

klystron number #1 to # 25 and the 1000 kW tube is assigned from #26 to #71. The peak beam power for each klystron is given from dividing the peak RF power by the klystron efficiency. Table 2 summarizes these results. The CW operation with lower output power is inefficient in comparison with the pulse operation. The total beam power of 57.1 MW and 20.7 MW is required at pulse and CW operation, respectively. We calculated the total AC power taking into account the pulse duty. But efficiency of DC-AC conversion is neglected, which is estimated to be about 90-95 %. Duration of about 0.7 ms is needed to rise the accelerating field in the SC cavity, then the duty becomes to 0.33. Total AC power is required about 20 MW at both operations.

Table 2. Summary of power estimation for SC linac.

	Pulse operation	CW operation
Proton beam current (mA)	18	5.33
Total peak RF power (MW)	29.1	8.61
Averaged klystron effi. (%)	50.8	41.5
Total beam power (MW)	57.1	20.7
Duty	0.33	1
Total AC power (MW)	18.4	20.7

3.3 Another choice of RF system

Another choice of the SC linac RF system is a way of one-cavity driven by one-IOT (Inductive Output Tube). This system is regarded as a suitable system for an RF control. In addition, the IOT is compact and is kept high efficiency at lower output power. In a rough estimation, the AC power at CW operation is reduced to 16 MW. However, high power IOT (more then 120kW) does not exist at present. Further if the IOT is applied as all amplifiers, 568 tubes including pre-amplifiers are needed. Using many tubes may cause reducing of accelerator reliability.

4 SUMMARY

We have studied the preliminary components for the RF system of the NSP accelerator. In the conceptual design, The NSP accelerator will require the total peak RF power of about 300 kW for the RFQ, 9 MW for the DTL and 29 MW for the SC linac. From viewpoint of the power dissipation on the screen grid mesh, a tetrode 4CM2500KG is an available tube as the amplifier in 200 MHz part. And a Diacrode is also regarded as a hopeful candidate although quantitative estimation is necessary. In the SC linac RF system that a klystron output power is distributed to four cavities, the required AC power is about 20 MW for pulse and CW operation. We will study the RF system design using the IOT tube.

5 REFERENCES

[1] M.Mizumoto et al,: 'A high intensity proton linac development for neutron science rerearch program', Proc. of the 18th Int. Liner Accelerator Conf., Geneva, Switzerland, p662 (1996)

[2] Y. Honda et al,: 'A conceptual design study of superconducting proton linear accelerator for neutron science project', Proc. of the 1st Asian Particle Accelerator.